# K-Ar Age Determination of an Ohio Basement Rock from Scioto County, Ohio

by

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## Abstract

The problem that was researched for this thesis involved the determination of K-Ar dates of biotite and hornblende mineral separates from an amphibolite-gneiss contact zone in the western portion of the Grenville basement of Ohio. The sample was taken from a well drilled by U.S. Steel Corp., Scioto County, Ohio.

It was anticipated that the hornblende might yield a pre-Grenville date since it retains argon at a higher temperature than biotite, thus explaining the contact between the older volcanics to the west, being at a higher elevation than the younger metamorphics to the east. The results gave a Grenville date of 957 m.y. which suggests the following possibilities: 1) the ages to the west are not accurate, they are much younger than stated 2) the contact is a result of faulting in the area or 3) the volcanics were not entirely exposed to metamorphism as were the rocks to the east which resulted in argon loss and younger ages. The resulting data was used in a reconstruction of the tectonic history of the Grenville in Ohio and was shown in a model.

## Acknowledgments

The author would like to sincerely thank Dr. John Sutter of The Ohio State University for his suggestion of the problem, for all his help during the course of this study and his critical advice in the writing of the paper. Mr. John Popek must also be thanked for his assistance in the laboratory and Nancy Ratterman for her help in reading and compiling the data from the mass spectrometer.

## I. Introduction

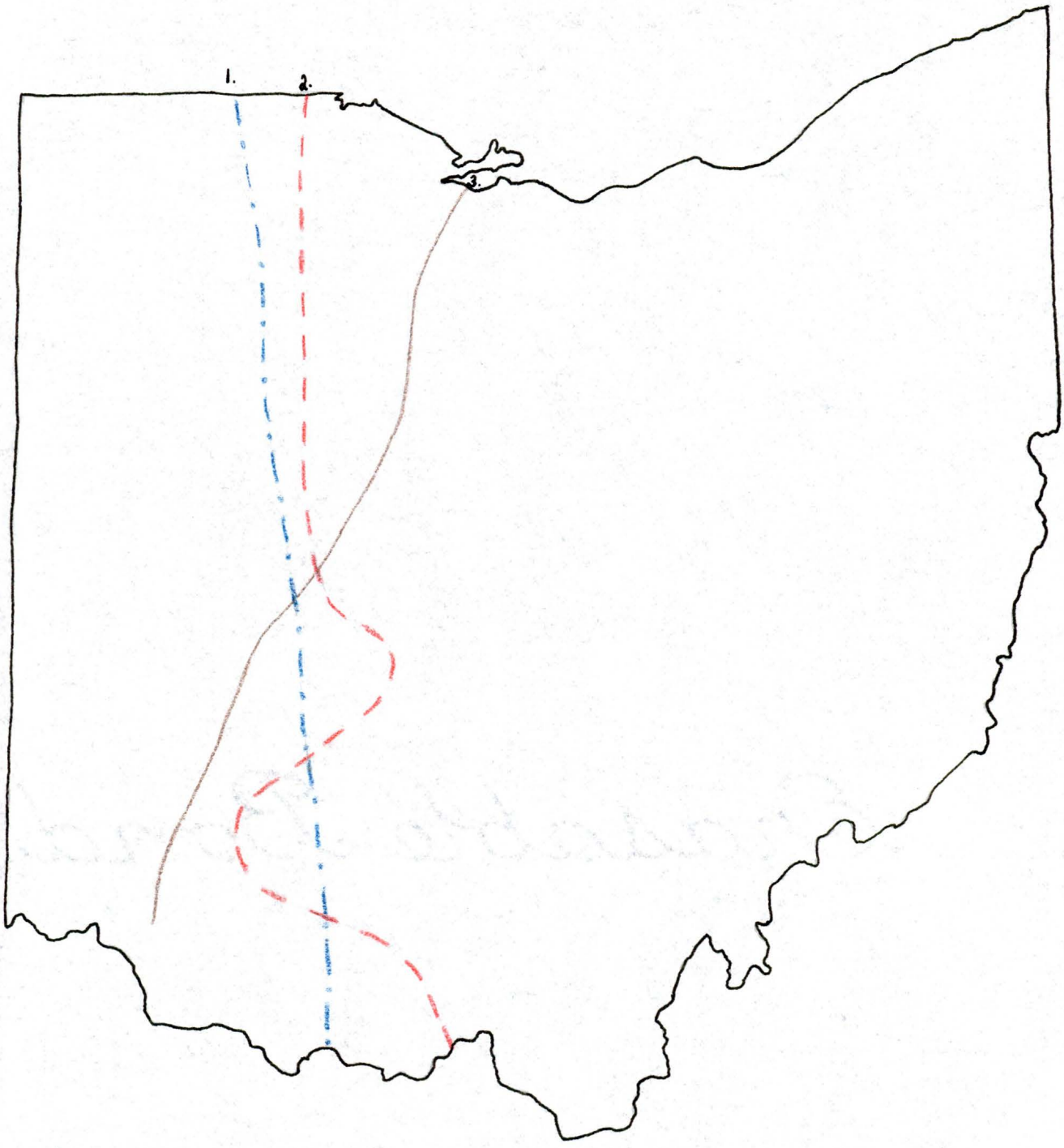
### Presence and Spatial Distribution of Grenville Province Rocks in Ohio

Geologists have placed the Grenville boundary at various locations in Ohio employing varying criteria for their decision.

Bass (1960) placed the western boundary of the Grenville Province in western Ohio (Figure 1). He placed the boundary on the basis of a drastic change in lithologic character of the rocks found on either side of the imaginary line. To the east of this boundary, the rocks are high-grade metamorphics; amphibolites, mica and hornblende schists and gneisses as well as minor amounts of marble and pegmatite. On the western side of the boundary, the rocks consist of an interlayered sequence of extrusive igneous and sedimentary rocks. The igneous rocks are primarily massive to flow banded aphanitic volcanics of intermediate composition. Several wells have also contained minor amounts of syenite and tuffs. Most of the sedimentary rocks found in the area are gray carbonaceous limestones.

Hofmann, Faure, and Janssens (1972) have placed the boundary close to Bass' boundary of the Grenville. Their criteria was simply the change in age of the rocks in the area (Figure 1). Trachytes and rhyolites to the west yielded Rb-Sr model dates on whole rocks of 1280±70 and 1240±120 m.y., respectively; whereas to the east, biotites and muscovites of metamorphic rocks have yielded Rb-Sr and K-Ar ages ranging from 860 to 990 m.y. (Lidiak, 1966).

McCormick (1961) has placed the Grenville boundary a little




Legend

1. Bass(1960)

2. Hofmann, Faure, Janssens(1972)

3. McCormick(1961)

Figure 1. Map showing boundaries of the Grenville basement rock in Ohio after Bass(1960), Hofmann, Faure and Janssens (1972), McCormick(1961).

0 10 20 30 40

SCALE IN MILES

further to the west of the two previously mentioned Grenville boundaries (Figure 1). His criteria was also based on the change of the lithologic character of the rocks to the east and to the west of this line. To the east marbles, hornfels and amphibolites, with accompanying granite gneiss and pegmatite make up the lithology and to the west are granite, syenite, latite, trachyte, and a small amount of biotite schist.

Previous Age Determinations

Numerous ages have been determined for the basement rocks of Ohio and in some cases these ages have been used to decide where to place the Grenville boundary. Bass (1960) reported Rb-Sr model ages of 900 to 1000 m.y. for micas from the eastern metamorphic rocks. He estimated that the volcanic rocks to the west are correlatives of granitic rocks of the Arbuckle Mountains, the St. Francis Mountains, and southern Wisconsin dated by Aldrich, et al (1959) as 1.35 to 1.45 b.y. on the basis of Rb-Sr. Bass thinks that the volcanic and granitic rocks of the central U.S., including those in western Ohio, are part of a largely or possibly wholly non-orogenic igneous province, thus giving the rocks west of the boundary older ages than those east of the boundary.

Age determinations of the basement rocks of Ohio and adjoining states have been carried out and are summerized in Table 1.

Introducing the Problem

The problem that was researched for this thesis involved the determination of K-Ar dates of biotite and hornblende mineral separates from an amphibolite-gneiss contact zone in the western portion of the Grenville basement of Ohio. No ages of

Table 1

| Well Name | County | Lithology | Rb-Sr Age(my) | K-Ar Age(my) |
|---|---|---|---|---|
| Vance | Delaware | Gran. & Hnb. Gneiss | 950(B),(M)[1,4]<br>900(B),(M)[3] | 880(M)[3]<br>940(B)[3] |
| Wilson | Fayette | Amp. & Granitic Pegmatite | 880(B)[3]<br>930(B)[1,4] | 990(B)[3] |
| Barnes | Fayette | Trachyte Porph. | 940[1] | |
| Hopkins | Fayette | Amp., Pegmatite, & Marble | 890(B),930(M)[3]<br>940(B),980(M)[1,4] | 930(M)[3]<br>980(B)[3] |
| Arting | Huron | Gran. Gneiss | 870(B)[3]<br>920(B)[1,4] | 935(B)[3] |
| Bruns | Sandusky | Gran. & Amp. | 890(B)[3]<br>940(B)[1,4] | 935(B)[3] |
| Killian | Wood | Gran. Gneiss | 900(B)[3]<br>950(B)[1,4] | 960(B)[3] |
| Nelson | Shelby | Trachyte Porph. | 1280(R)[3] | |
| Johns | Logan | Rhyolite Porph. | 1240(R)[3] | |
| Myers | Morrow | Biotite Gran. | 860(B)[3] | |
| U.S. Steel | Scioto | Gran. Gneiss | 898(B)[5] ← | 1242(F)[5] |
| Calhio Chemicals | Lake | Chlorite Schist | 566(R)[6] | |
| Taylor | Lenawee | Gran. & Granitic Gneiss | 890-970[1] | |
| Beaver Isl. | Charlevoix | | 1040(B)[3] | 1090(B)[3] |
| Hurst | St. Clair | Biotite Gneiss | 900(B)[3] | 970(B)[3] |
| Voss | Washtenaw | Gneiss | 840(B)[3] | |
| Meinzinger | Washtenaw | Gneiss | 920(B)[3] | |
| Bethlehem Steel | Porter | Biotite Gran. | 1340(F)[3] | |
| Greentown | Howard | Hnb. Granite | 1240(F)[3] | |
| May | Henry | Micrographic Gran. | 1090(F)[3] | |
| Doddridge | Wayne | Micrographic Gran. | 1080(F)[3] | |
| Power Oil Company | Wood | Granodiorite Gneiss | 820(B)[3]<br>870[1] | 850(B)[3] |

References:

[1] Summerson(1962)
[2] Bass(1960)
[3] Lidiak, et al (1966)
[4] McCormick(1961)
[5] Hofmann(1972)
[6] Vargo(1972)

A = Ohio
B = Michigan
C = Indiana
D = West Virginia

Gran. = Granite
Hnb. = Hornblende
Amp. = Amphibolite
Porph. = Porphyry

B = Biotite
M = Muscovite
F = Feldspar
R = Whole Rock

hornblende have previously been reported from the Ohio basement and it was anticipated that the hornblende might yield a pre-Grenville date since it retains argon at a higher temperature than biotite. If indeed the hornblende gave a date of >1.2-1.3 b.y., then the possibility of the volcanic rocks in western Ohio being 1.2-1.3 b.y. in age would seem more plausible. Old amphibole ages (~1.4-1.5 b.y.) have been reported from the Grenville Province in Canada (Hartung, et al, 1971). If the volcanic rocks to the west are indeed older than Grenville metamorphism, as the isotopic data of Hofmann, Faure, and Janssens (1972) suggests, the problem of the nature of the contact between these two units is quite severe. With the older volcanics to the west at a higher elevation than the younger metamorphics to the east, thrust faulting of the volcanics might have been considered, but with more Grenville age rocks found further west of the volcanics into Indiana and Illinois (Summerson, 1962) this possibility seemed unlikely. Since there is little or no metamorphic effect on the volcanics from the surrounding area, which was highly metamorphosed as is shown by the presence of high-grade metamorphic rocks, the possibility of the volcanics having overlain the metamorphics as younger rocks but unaffected by the later metamorphism also seemed unlikely.

With the results from this experiment and some fundamental assumptions, a model for the post-Grenville tectonic history of the Ohio basement has been constructed and compared to similar models for other parts of the Grenville Province. This data also has a strong bearing on the nature of the metamorphic rock-

volcanic rock contact in western Ohio and indirectly has a bearing on the possible age of the volcanics.

II. Core and Rock Specimen Descriptions

The amphibolite sample used in this study came from a portion of core from the U.S. Steel Well in Green Township of Scioto County about 40-60 miles east of the proposed Grenville boundary (Figure 2). The following petrographic description is based on Gonterman (1972). The well was drilled to a total depth of 5614 feet, the last 22 feet being Precambrian rock. Lithologic changes in the core are seen at depths of 5601 and 5605.5 feet. A closer look at the Precambrian section of the core shows a medium to coarse-grained pinkish gray and dark gray gneiss which varies in lithology with depth.

Between the depths of 5595-5601 feet, the rock is mostly salmon to reddish pink, coarse grained and composed of potassium feldspar, plagioclase, chlorite, biotite and magnetite. Parallel orientation of the biotite and chlorite grains results in well-developed foliation. The next interval, 5601-5605.5 feet, shows a medium to dark gray coarse-grained gneiss and minor amphibolite. Hornblende is abundant and the biotite:chlorite ratio is greater than in the next higher interval. Compositional banding occurs in this interval with the dark bands being biotite, chlorite and hornblende, the light bands are reddish gray and composed of plagioclase, potassium feldspar, and quartz. Below a depth of 5605.5 feet, there are thinner compostional bands, otherwise the sample is the same as in the above interval. A scaled diagram of the Precambrian section of the core is shown in Figure 3.

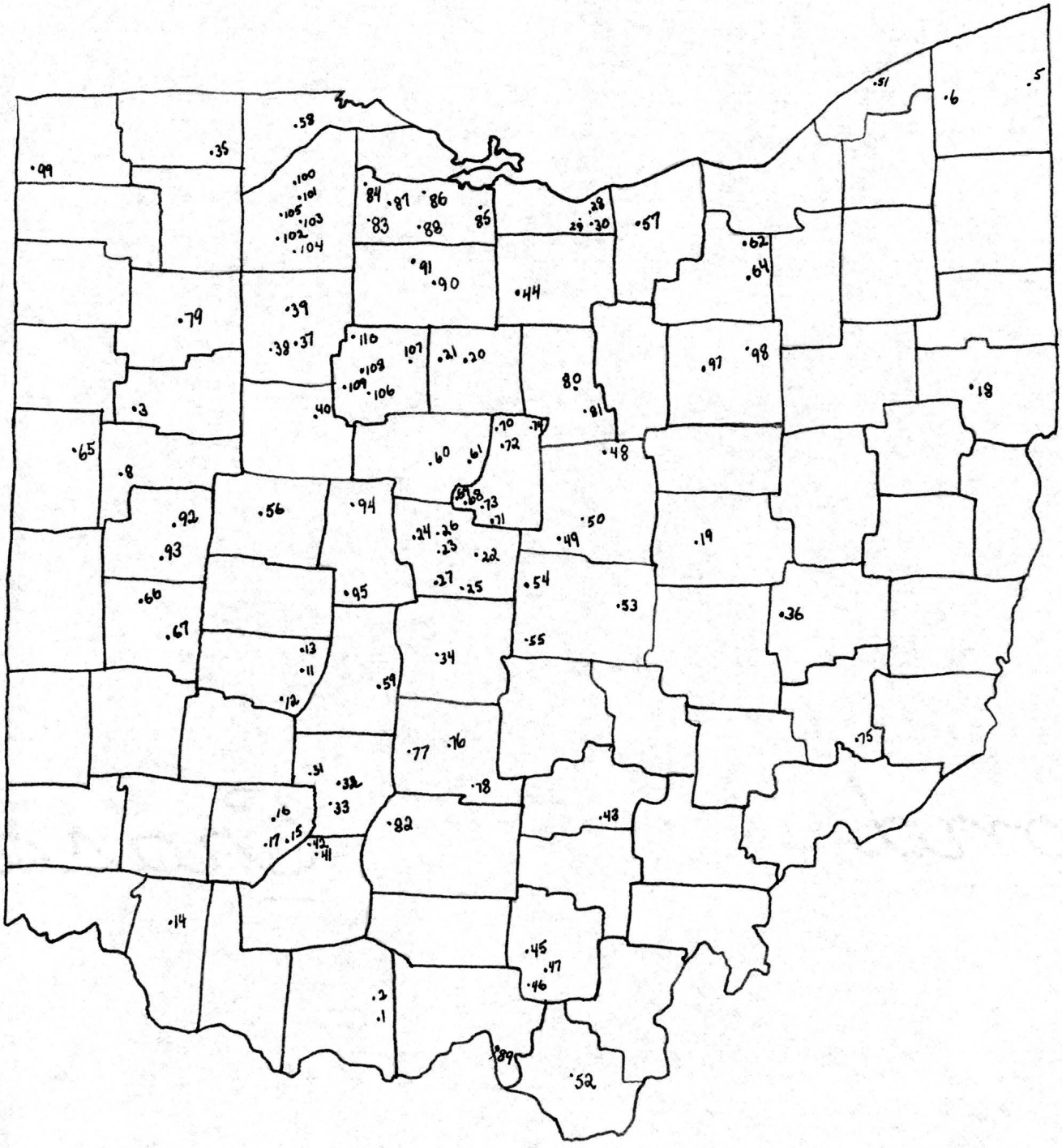



Figure 2. Map of Ohio showing the location of wells drilled to the Precambrian; wells 4,7,9,10,23,43,63,96 are not shown on the map.

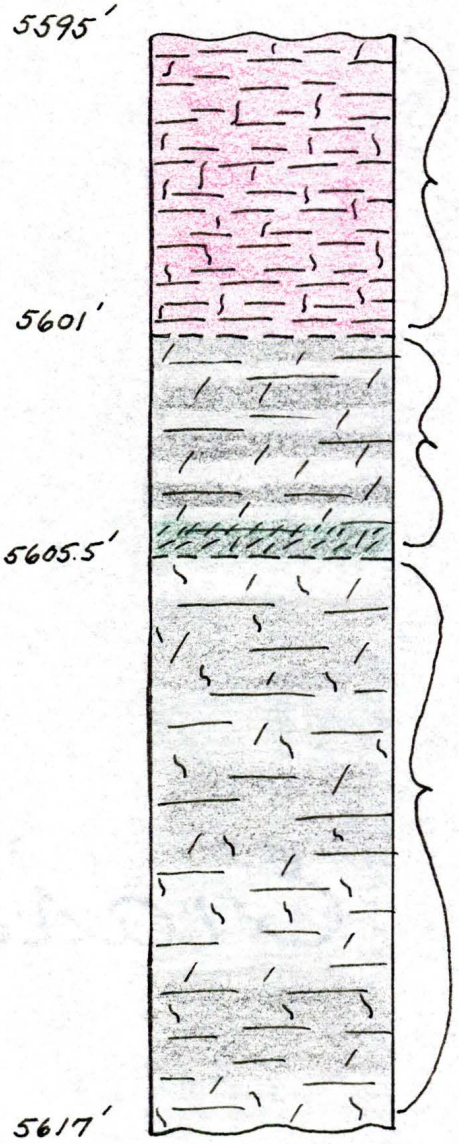



Figure 3. Scaled diagram of the Precambrian section of the core sample.

The sample used for the age determination was found at a depth of 5605.5 feet and its dimensions were 3.5 in. by 1.5-2 in. thick. The sample was taken from a gneiss-amphibolite contact where hornblende and biotite were abundant. Microscopic inspection revealed the main mineral constituents as being biotite, hornblende, plagioclase, quartz and magnetite.

Table 2 lists all the wells in Ohio to the present that have penetrated basement rock. Depths to the Precambrian surface are also included.

## III. Experimental Procedures

### Sample Preparation

A portion of the core containing a biotite gneiss-amphibolite contact was chosen in order to obtain both biotite and hornblende mineral separates. About one-third or one-fourth of this portion of the core was sawed off and reserved for future experiments. The remaining portion was then crushed and sieved. Inspection of the various size fractions was made using a binocular microscope and those fractions containing the largest percentage of biotite and hornblende as individual grains were retained for mineral separations.

#### 1) Separation of biotite

The percentage of individual biotite grains was highest in the 35/60 mesh size fraction. This fraction was washed first with distilled water, then alcohol to remove unwanted dust and then dried in an oven at about 100-110° C. The heavy minerals, including biotite, hornblende and magnetite were separated from the quartz, feldspars and other less dense minerals by the use

Table 2 List of all the wells in Ohio that penetrate the Precambrian; other data given if available.

| Ref. No. | County | Well Name | Depth to Pc. | Cutting | Core | Date Drilled |
|---|---|---|---|---|---|---|
| 1 | Adams | Bailey | 3740 | | | 1964 |
| 2 | Adams | Covert | 3772 | | | 1965 |
| 3 | Allen | Pohlman | 3186 | | | 1964 |
| 4 | Allen | Standard Oil | 3148 | | | 1971 |
| 5 | Ashtabula | Brayman | 6915 | | | 1965 |
| 6 | Ashtabula | Rhoa | 6740 | | | 1965 |
| 7 | Ashtabula | Roulston | 6606 | | | 1970 |
| 8 | Auglaize | Hoelscher | 2942 | | | 1970 |
| 9 | Butler | Armco Steel Corp. | NA | | | 1968 |
| 10 | Clark | Brown | 3597 | | | NA |
| 11 | Clark | Elcamere Farms | 3535 | | | 1964 |
| 12 | Clark | Friend | 3368 | | | 1926 |
| 13 | Clark | R & E Brown | 3624 | | | 1962 |
| 14 | Clermont | Wickoff | 3310 | | | 1960 |
| 15 | Clinton | Adams | 3390 | x | | 1958 |
| 16 | Clinton | McVey | 3465? | x | | 1959 |
| 17 | Clinton | Van Pelt | 3210 | x | | 1959 |
| 18 | Columbiana | Marray | 10,200 | | | 1970 |
| 19 | Coshocton | Lee | 6947 | | | 1971 |
| 20 | Crawford | Leonhardt | 3770 | | | 1965 |
| 21 | Crawford | Spitler-Brown Unit | 3410 | | | 1965 |
| 22 | Delaware | Gregory | 4685 | | | 1965 |
| 23 | Delaware | H & H Smith | 3990 | | | 1965 |
| 24 | Delaware | Jones | 3422 | | | 1964 |
| 25 | Delaware | Lindsey | 4053 | | | 1965 |
| 26 | Delaware | Sprain | 3994 | | | 1962 |
| 27 | Delaware | Vance | 3810 | x | | 1934 |
| 28 | Erie | Herman | 4450 | | x | 1966 |
| 29 | Erie | Krysek-Wakefield | 4455 | | | 1966 |
| 30 | Erie | Sayler | 4400 | x | | 1960 |
| 31 | Fayette | Barnes | 3380 | x | | 1958 |
| 32 | Fayette | Hopkins | 3545 | x | x | 1957 |
| 33 | Fayette | Wilson | 3340 | x | | 1957 |
| 34 | Franklin | Marble Cliff | 3620 | | | 1965 |
| 35 | Fulton | Storeholder | 3554 | | | 1970 |
| 36 | Guernsey | Marshall | 8330 | x | | 1961 |
| 37 | Hancock | Drummelsmith | 2800 | | | 1966 |
| 38 | Hancock | Frazier | 3015 | | | 1964 |
| 39 | Hancock | Norris | 2770 | | | 1912 |
| 40 | Hardin | Jones | 2791 | | | 1962 |
| 41 | Highland | Courtney | 3605 | | | 1972 |
| 42 | Highland | Pavey | 3482 | | | 1959 |
| 43 | Hocking | Hockman | 6469 | | | 1966 |
| 44 | Huron | Arting | 3901 | x | | 1937 |
| 45 | Jackson | Brown | 5990 | | | 1964 |

| Ref. No. | County | Well Name | Depth to Pc. | Cutting | Core | Date Drilled |
|---|---|---|---|---|---|---|
| 46 | Jackson | Slavens | 5575 | | | 1964 |
| 47 | Jackson | Wood | 6218 | | | 1964 |
| 48 | Knox | Cunningham | 5640 | | | 1961 |
| 49 | Knox | Huffman | 4780 | | | 1964 |
| 50 | Knox | Larimore | 5355 | | | 1963 |
| 51 | Lake | Calhio Chemical | 6060 | | x | 1971 |
| 52 | Lawrence | Payne | NA | | | 1963 |
| 53 | Licking | Crowley | 5980 | | | 1961 |
| 54 | Licking | Roberts | 4910 | | | 1964 |
| 55 | Licking | Schmelzer | 4785 | | | 1965 |
| 56 | Logan | Johns | 3255 | x | x | 1947 |
| 57 | Lorain | Born | 4570 | x | | 1960 |
| 58 | Lucas | Ketring | 3623 | | | 1972 |
| 59 | Madison | Hume | 3614 | | | 1965 |
| 60 | Marion | Gruber | 3449 | | | 1964 |
| 61 | Marion | Mitchell | 3672 | | | 1962 |
| 62 | Medina | Smith | 6930 | x | x | 1959 |
| 63 | Medina | Wandel Unit | 5667 | | | 1973 |
| 64 | Medina | Warner | 6650 | x | | 1959 |
| 65 | Mercer | Yewey | NA | | | 1971 |
| 66 | Miami | Levering | 3282 | x | | 1955 |
| 67 | Miami | Walker | 3255 | x | | 1958 |
| 68 | Morrow | Bush | 3864 | | | 1964 |
| 69 | Morrow | Henry | 4008 | | | 1962 |
| 70 | Morrow | Irey | 3870 | | | 1965 |
| 71 | Morrow | McBee | 4435 | | | 1964 |
| 72 | Morrow | Myers #3 | 3996 | | | 1961 |
| 73 | Morrow | Shaver-Neff | 4195 | | | 1964 |
| 74 | Morrow | Windbigler | 4872 | | | 1962 |
| 75 | Noble | Ullman | 11,420 | | | 1967 |
| 76 | Pickaway | Croman | 3685 | | | 1963 |
| 77 | Pickaway | Long | 3145 | x | | 1959 |
| 78 | Pickaway | Miller | 4148 | | | 1964 |
| 79 | Putnam | Barlage | 3350 | x | | 1944 |
| 80 | Richland | Empire Reeves | 5085 | | x | 1967 |
| 81 | Richland | Scott | 5483 | | | 1966 |
| 82 | Ross | Clark | 3845 | | | 1964 |
| 83 | Sandusky | Aleshire-Marathon | 2756 | | | 1965 |
| 84 | Sandusky | Bruns | 2667 | x | | 1902 |
| 85 | Sandusky | Haff | 3090 | x | | 1960 |
| 86 | Sandusky | Hetrick | 2701 | | | 1936 |
| 87 | Sandusky | Kerbel | 2735 | | | 1965 |
| 88 | Sandusky | Recker | 2615 | | | 1965 |
| 89 | Scioto | U.S. Steel | 5580 | | x | 1968 |
| 90 | Seneca | Stigamire | 3147 | | | 1965 |
| 91 | Seneca | Watson | 2900 | | | 1912 |
| 92 | Shelby | Fogt | 3288 | x | | 1956 |
| 93 | Shelby | Nelson | 3140 | x | | 1955 |
| 94 | Union | Lane | 2985 | | | 1964 |

| Ref. No. | County | Well Name | Depth to Pc. | Cutting | Core | Date Drilled |
|---|---|---|---|---|---|---|
| 95 | Union | Zenith | 3348 | | | 1961 |
| 96 | Van Wert | Miller | 3214 | | | 1972 |
| 97 | Wayne | Drake | 6700 | | | 1965 |
| 98 | Wayne | Steiner #2 | 6904 | | | 1961 |
| 99 | Williams | Kennerk | 3925 | | | 1965 |
| 100 | Wood | Asmus | 2800 | | | 1965 |
| 101 | Wood | Carter | 2810 | | | 1965 |
| 102 | Wood | Killian | 2884 | x | | 1937 |
| 103 | Wood | Knauss | 2720 | | | 1964 |
| 104 | Wood | Peek | 2760 | | | 1964 |
| 105 | Wood | Smith | 2773 | | | 1965 |
| 106 | Wyandot | Bowen | 2850 | | | 1964 |
| 107 | Wyandot | Eyestone | 3240 | | | 1965 |
| 108 | Wyandot | Frey | 2862 | | | 1964 |
| 109 | Wyandot | Parsell | 3040 | | | 1947 |
| 110 | Wyandot | Heck | 2795 | x | | 1942 |

References:

Gonterman (1972)
McCormick (1961)
Ohio Geological Survey
Owens (1967)
Summerson (1962)

of bromoform, a heavy liquid whose specific gravity is 2.88. The heavy minerals were then washed with acetone, distilled water and alcohol, and dried in an oven. After drying, magnetite was removed by use of a hand magnet. The remaining sample was then passed through a Frantz Isodynamic magnetic separator to remove any other highly magnetic minerals and any essentially non-magnetic minerals. That portion remaining was a relatively pure biotite plus hornblende concentrate. This was papershaken to separate the biotite from the hornblende. Since the biotite flakes are platy, they adhere somewhat to the filter paper but the angular grains of hornblende fall off. The biotite separate was checked for purity under a binocular microscope and found to be $>99\%$ pure. The pure biotite was washed with acetone, distilled water and alcohol and dried at 100°C. After drying, the biotite was sieved again and the -35,+48 size fraction was stored in a clean, labeled glass vial for use in both the K and Ar analysis.

2) Separation of hornblende

The same procedure was used for purifying the hornblende with only one additional step. After the heavy minerals were separated by the use of bromoform, the fraction containing the hornblende, biotite and magnetite was washed with acetone, distilled water and alcohol and dried at about 100°C. These minerals were further separated in a separatory funnel by the use of methylene iodide which has a specific gravity of 3.3. The magnetite grains sank in concentrated methylene iodide and were discarded. A small amount of acetone was then added to the methylene iodide, lowering its specific gravity. The grains that sank from the new-

ly diluted methylene iodide were collected and examined under a binocular microscope. The percentage of individual hornblende grains in this fraction was very high, so it was saved for further purification. The hornblende was further purified to >99.9% by papershaking. The hornblende was then sieved and the -48,+80 mesh size fraction was washed and dried and stored in a clean, labeled glass vial for use in both the K and Ar analysis.

Potassium Analysis

Three aliquants each of the biotite and hornblende separates were weighed out in platinum crucibles, about 0.05 grams for the biotite and about 0.1 grams for the hornblende. Biotite requires less material than the hornblende in making potassium solutions because of biotite's high potassium content. An aliquant of U.S.G.S. rock standard G-2 (a granite) was also included as a reference sample.

Sulfuric and hydroflouric acids were added to the crucibles which were then heated overnight at ~90°C. to allow volatization of Si as $SiF_2$. The second day nitric acid was added to each crucible which were then placed on a hot plate and advanced in temperature until strong white fumes from sulfuric acid became apparent. Distilled water was added to the crucibles which were then placed on a hot plate at ~90°C. until everything was in solution. Solutions were then transferred to Erlenmeyer flasks and neutralized with a 33% $NH_4OH$ solution causing the precipitation of Fe and Al oxides and their complexes ($R_2O_3$ group) as hydroxides. Ammonium carbonate was added to each in order to precipitate excess Ca as $CaCO_3$ and then left to stand overnight. The solutions were then

filtered through Whatman 40 quantitative papers with the filtrates being collected in 500 ml. volumetric flasks. The filter papers were washed three times with distilled water to insure that all $K^+$ had been collected in the volumetric flasks. To each volumetric flask, now which contained mainly the Na, K, and Mg, a concentrated lithium buffer solution was added and the solutions were then diluted to volume, mixed and an aliquant of each stored in a labeled 4 ounce polyethylene bottle.

The solutions were now ready for analysis on the flame photometer, a Zeiss PF-5. The flame photometer operates on the principle that all elements emit radiation of a characteristic wavelength, $\lambda$, when going from an "excited" state back to the "ground" state. Most elements need very high temperatures for excitation, but the alkali metals need only to be heated in a propane-air flame. The concentration of the element is directly proportional to the intensity of the radiation. The flame photometer uses these properties of elements and compares the intensity of the potassium radiation from the unknown with that of two potassium standards, one of lower potassium concentration and the other of higher potassium concentration. The potassium concentration of the unknown is then found by linear interpolation. Once the concentration of K in solution has been found, the percent K in the sample is calculated by dividing the concentration by the weight of sample that was originally put into solution. The data from this portion of the experiment is listed in Table 3.

Argon Extraction and Analysis

Once the percent of potassium is known for the sample the

| Crucible # | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| Material | Biotite | Biotite | Biotite | Hnb | Hnb | Hnb | Analyzed Granite G-2 |
| Sample wgt. | 0.05072 | 0.05142 | 0.05093 | 0.10079 | 0.10020 | 0.10038 | 0.07034 |
| High Standard (ug/ml) | 9 | 9 | 9 | 3 | 3 | 3 | 6 |
| Average Reading on Photometer | 32.00 | 32.00 | 31.87 | 36.50 | 36.50 | 36.27 | 33.87 |
| Low Standard (ug/ml) | 8 | 8 | 8 | 2 | 2 | 2 | 5 |
| Average Reading on Photometer | 28.60 | 28.60 | 28.40 | 23.83 | 23.83 | 23.53 | 27.73 |
| Samples Average Reading on Photometer | 28.20 | 28.73 | 28.33 | 28.15 | 28.20 | 27.80 | 29.47 |
| % K | 7.7701 | 7.8160 | 7.8342 | 1.1618 | 1.1707 | 1.1636 | 4.5243 |

Table 3. Listing of the standards used, readings off the flame photometer, weight of the sample, and % K for the samples measured.

amount of sample necessary for argon extraction can be calculated. The K-Ar nomogram (Dalrymple,Lanphere, 1969) is a quick, easy way to do this. Knowing: 1) potassium in weight percent expressed as either $K_2O$ or K and 2) the estimated age in millions of years. The quantity of radiogenic $^{40}Ar$, expressed in units of either moles/gram or cc STP/gram, can be determined by drawing a straight line through the % K, and estimated age and extending it to the $^{40}Ar$ column of the nomogram. The value of $^{40}Ar_{rad.}$ (cc STP/gram) is divided by the measured sensitivity of the mass spectrometer (cc STP $^{40}Ar_{rad.}$/mv of signal from the vibrating reed electrometer). This quotient is expressed in mv/gram of sample. The amount of sample to be loaded can be calculated by dividing the known millivolts of $^{38}Ar$ in the tracer by the quotient obtained above and multiplying the result by the number of grams needed to make the $^{40}Ar/^{38}Ar$ ratio about two. The data used for the calculation of biotite and hornblende sample weights in this experiment is listed in Table 4.

The argon extraction and purification line used in the O.S.U. K-Ar laboratory is shown diagrammatically in Figure 4. Each sample was weighed out and placed in a molybdenum crucible which was suspended in a pyrex sample bottle having a quartz liner. The bottle was sealed and joined to the extraction line. An $^{38}Ar$ tracer was also joined to the line. The extraction line was evacuated and baked at about 300°C. overnight. The bottle containing the sample was baked at about 80-100°C. with heating tapes. The purpose of baking the system was to facilitate the removal of adsorbed air and water vapor and to increase the effective pump-

| Sample | Biotite | Hornblende |
|---|---|---|
| % K | 7.825 | 1.1627 |
| Estimated Age (m.y.) | 950 | 1400 |
| $^{40}Ar_{RAD.}$ (cc STP/gm) | $3.9 \times 10^{-4}$ | $9 \times 10^{-5}$ |
| Sensitivity of Mass Spec. (cc STP $^{40}Ar_{RAD.}$/mv of signal) | $3 \times 10^{-9}$ | $3 \times 10^{-9}$ |
| $^{38}Ar_{SPIKE}$ (V) | 4V/gm | 3.88V/gm |
| Amount of Sample Needed | 0.08-0.09gm | .2gm |

Table 4. Listing of the data needed to calculate the biotite and hornblende sample weights necessary for age determinations in this experiment.

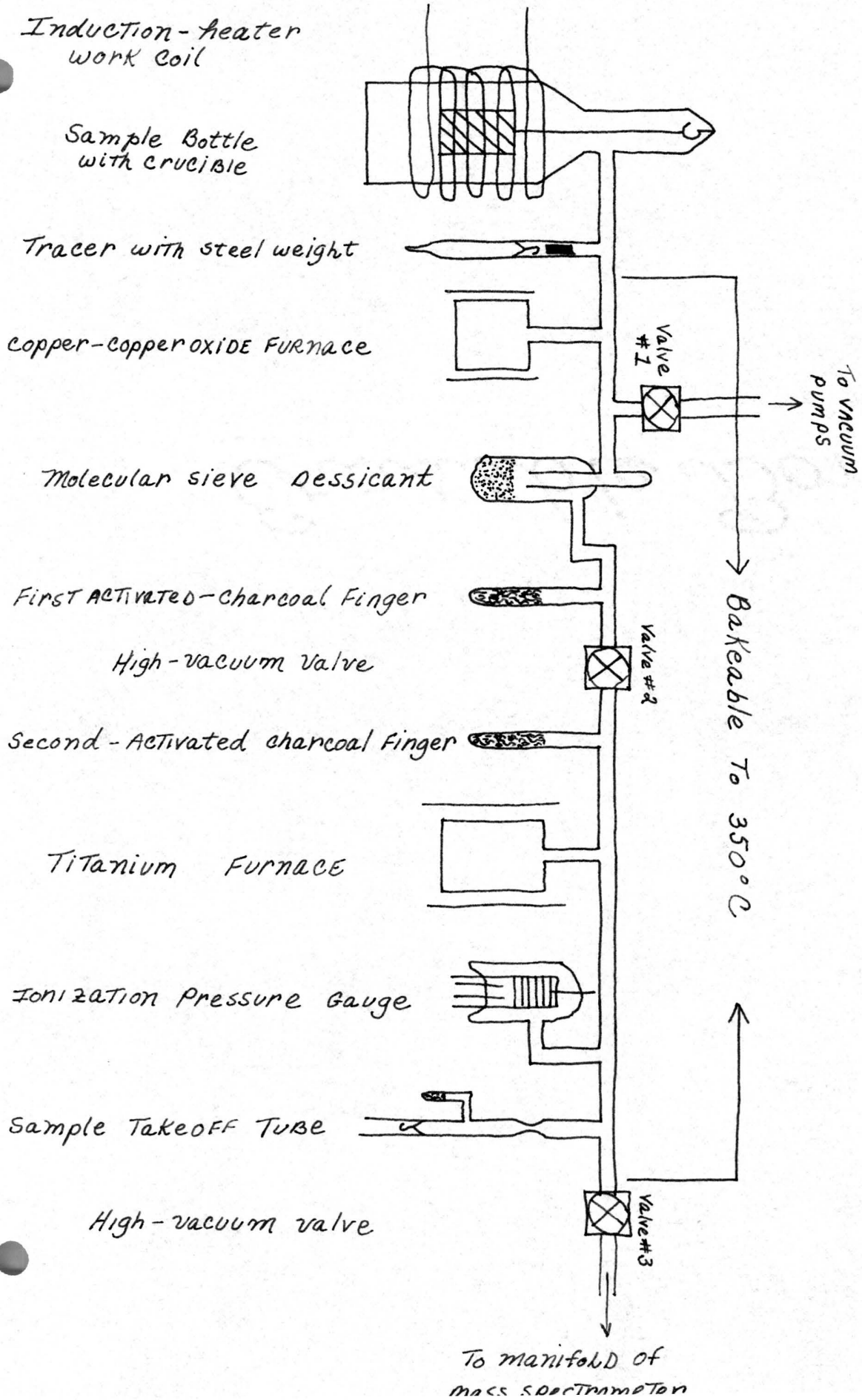



Figure 4. Schematic of argon extraction system. It is constructed of Pyrex glass except for the Cu-CuO and Ti furnaces and valves which are made of stainless steel.

ing speed of the vacuum pumps. The following morning the system was cooled, the pressure was checked (about $4 \times 10^{-8}$ Torr) and the system was checked for leaks.

Various sections of the extraction line were then isolated from the pumping system by closing valves #1, #2, and #3. An induction heating coil from a radio-frequency generator was placed around the bottle and the sample was melted. The coil induces a current flow in the crucible thus heating the crucible (molybdenum being a high resistance metal) without heating the sample bottle. Because there was slight heating of the bottle by radiation from the crucible, a forced-air blower fan was used to keep the bottle cool. While the sample was being fused, the tracer containing a known amount of $^{38}Ar$ was released into the system by using a magnet to drop a chiseled weight on the break-off tip. The gas that was liberated by the fusion and that of the tracer was collected on the first activated-charcoal finger which was cooled by being immersed in liquid nitrogen(-196°C.). After the sample had been fused and the sample bottle cooled, the charcoal finger was warmed, which released the gas, exposing it to a mixture of Cu and CuO at a temperature of 450°C. to 550°C. Hydrogen was oxidized to water and hydrocarbons were oxidized or burnt. Water vapor was absorbed by the synthetic molecular sieve. After twenty minutes the line was tested with a Telsa coil to be sure all the water had been absorbed. The gas was transferred to the Titanium section, between valves #2 and #3, using the second activated-charcoal finger immersed in liquid nitrogen.

After a ten minute transfer, valve #2 was closed and the gas released by warming the charcoal finger and exposed to titanium metal at 800°C. for twenty minutes and then the titanium was cooled to room temperature. The titanium removed all but the inert gases which were transferred directly to the third charcoal finger, which was also immersed in liquid nitrogen, by openning valve #3. After all the inert gas was collected, valve #3 was was closed and the sample was ready to be analyzed in the mass spectrometer, Figure 5.

A mass spectrometer is an instrument in which ions are analyzed according to the mass of the atoms or molecules present in the sample. This is the instrument that was used for determing the concentration of $^{40}Ar_{rad.}$ in the sample.

The type of mass spectrometer used in the O.S.U. K-Ar laboratory is the Nier-type. It is a first-order direction-focusing spectrometer with a 60° magnetic deflection and a 6 inch radius of curvature and is made of stainless steel. This instrument is operated in the static mode. The ion source is the filament type which uses a filament to produce electrons which then bombard the argon atoms as they enter the ionization chamber. The argon atoms may collide with electrons and become ionized. The energy of electrons used for ionization is about 50 volts in order to maximize the efficiency of single ionization and minimize multiple ionization. The ions are accelerated through a potential difference of three thousand volts developed between the ionization chamber and the source-object slit. As the ions emerge from the ion source they are traveling in a narrow beam at high velocities.

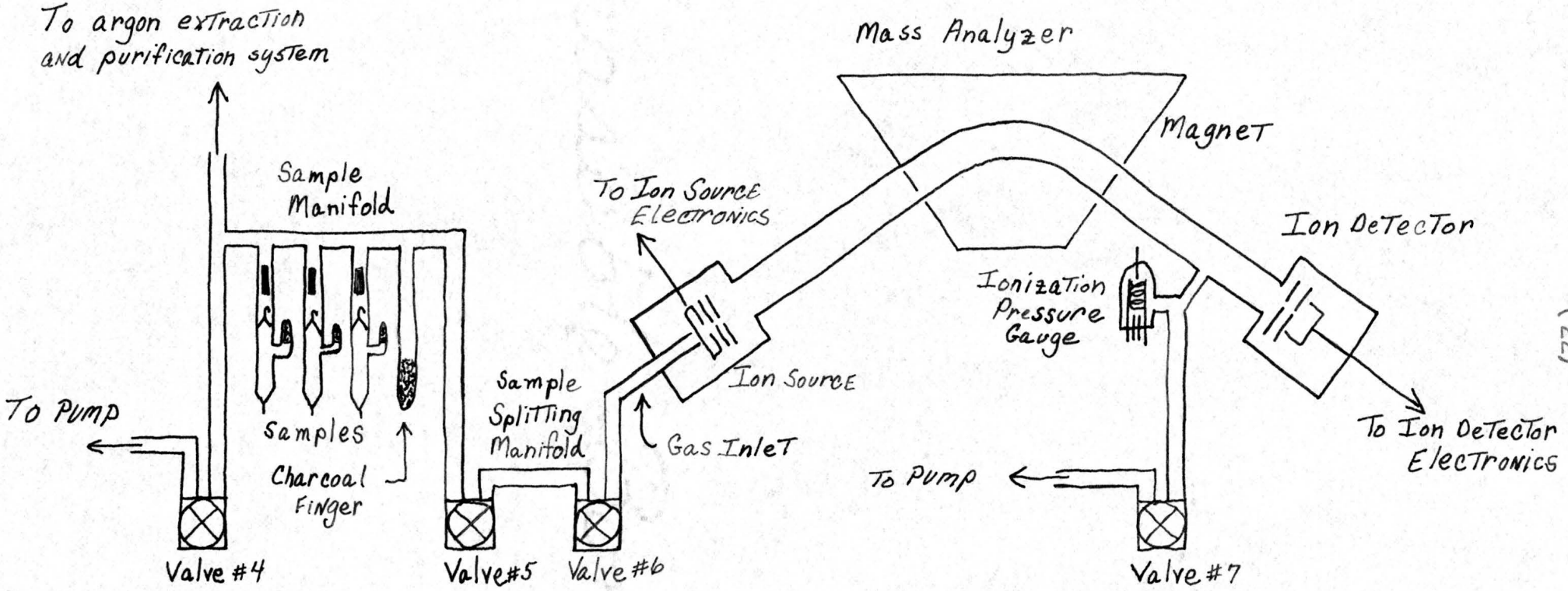



Figure 5. Schematic diagram of a mass spectrometer for argon analysis

This beam contains ions of all e/M values (e is the charge of the ion, M is the mass). The ion beam passes through the magnetic field, deflecting the ions into circular paths, the radii of which are inversely proportional to the square root of e/M. The ions have been separated into beams of particular e/M values. The ion beams are focused on a collector slit by varying the strength of the magnetic field and measured by a simple cage-type ion collector(faraday cup) which is connected to an amplifier known as a vibrating-reed electrometer. The amplifier is connected to am output device such as a strip-chart recorder.

The sample and tracer argon analyzed was first allowed to reach equilibrium in the manifold section, between valves #3 and #6, then valve #5, shown in Figure 5, was closed. With the strip chart recorder ready, a small portion of sample was admitted to the ion source by openning valve #6. This allowed the analyst to determine whether or not the argon was pure enough to be analyzed and determine if it could be analyzed on one of the scales of the Vibrating Reed Electrometer. When it was determined that the argon was capable of being analyzed, valve #5 was openned and all the argon was allowed to come to static equilibrium in the mass spectrometer. Once equilibrium was achieved, valve #6 was closed and the analysis begun. Twelve sets of $^{40}Ar$, $^{38}Ar$, and $^{36}Ar$ peaks were measured by changing the strength of the magnetic field.

## IV. Presentation of Data and Age Calculation

### $^{40}K$ Decay Scheme

The decay of $^{40}K$ is a branching process. The decay to $^{40}Ca$

occurs by the emission of a $\beta^-$ particle from the nucleus and the conversion of a neutron to a proton. The decay of $^{40}K$ to $^{40}Ca$ is hardly ever used for dating because the original $^{40}Ca$ present in the rock at the time of its formation is hard to distinguish from the $^{40}Ca$ produced by the decay of $^{40}K$. The decay of $^{40}K$ to $^{40}Ar$ which is used for K-Ar dating can occur by three different methods: 1) by electron capture, the most common. An electron is captured by the nucleus, unites with a proton to form a neutron. The argon atom is in an energetically excited state and quickly decays to ground state by emission of a gamma-ray. 2) a small percentage of the argon that decays by electron capture goes directly to ground state without the emission of a gamma-ray. 3) by the emission of a positron. This is very rare, only 0.001% of $^{40}K$ decays this way. The decay scheme of $^{40}K$ is shown in Figure 6.

The general formula for redioactive decay can be expressed in terms of the present day amounts of the parent and daughter atoms:

$$D = N(e^{\lambda t} - 1) \qquad (1)$$

to calculate the age, solve for t,

$$t = \frac{1}{\lambda}\left(\log_e\left(\frac{D}{N} + 1\right)\right) \qquad (2)$$

for branching decay with daughter products $D_1$ & $D_2$ formula (1) becomes:

$$D_1 + D_2 = N\left[e^{(\lambda_1 + \lambda_2)t} - 1\right] \qquad (3)$$

for the case of the decay of $^{40}K$ the formula is:

$$^{40}Ar_{rad.} + {}^{40}Ca_{rad.} = {}^{40}K\left[e^{(\lambda_\epsilon + \lambda_\beta)t} - 1\right] \qquad (4)$$

Making use of decay constants for geologic ages, formula(4) becomes:

$$^{40}Ar_{rad.} = {}^{40}K\,\frac{\lambda_\epsilon}{\lambda_\epsilon + \lambda_\beta}\left[e^{(\lambda_\epsilon + \lambda_\beta)t} - 1\right] \qquad (5)$$

and solving for t,

$$t = \frac{1}{\lambda_\epsilon + \lambda_\beta}\left(\log_e\left[\frac{^{40}Ar_{rad.}}{^{40}K}\left(\frac{\lambda_\epsilon + \lambda_\beta}{\lambda_\epsilon}\right) + 1\right]\right) \qquad (6)$$

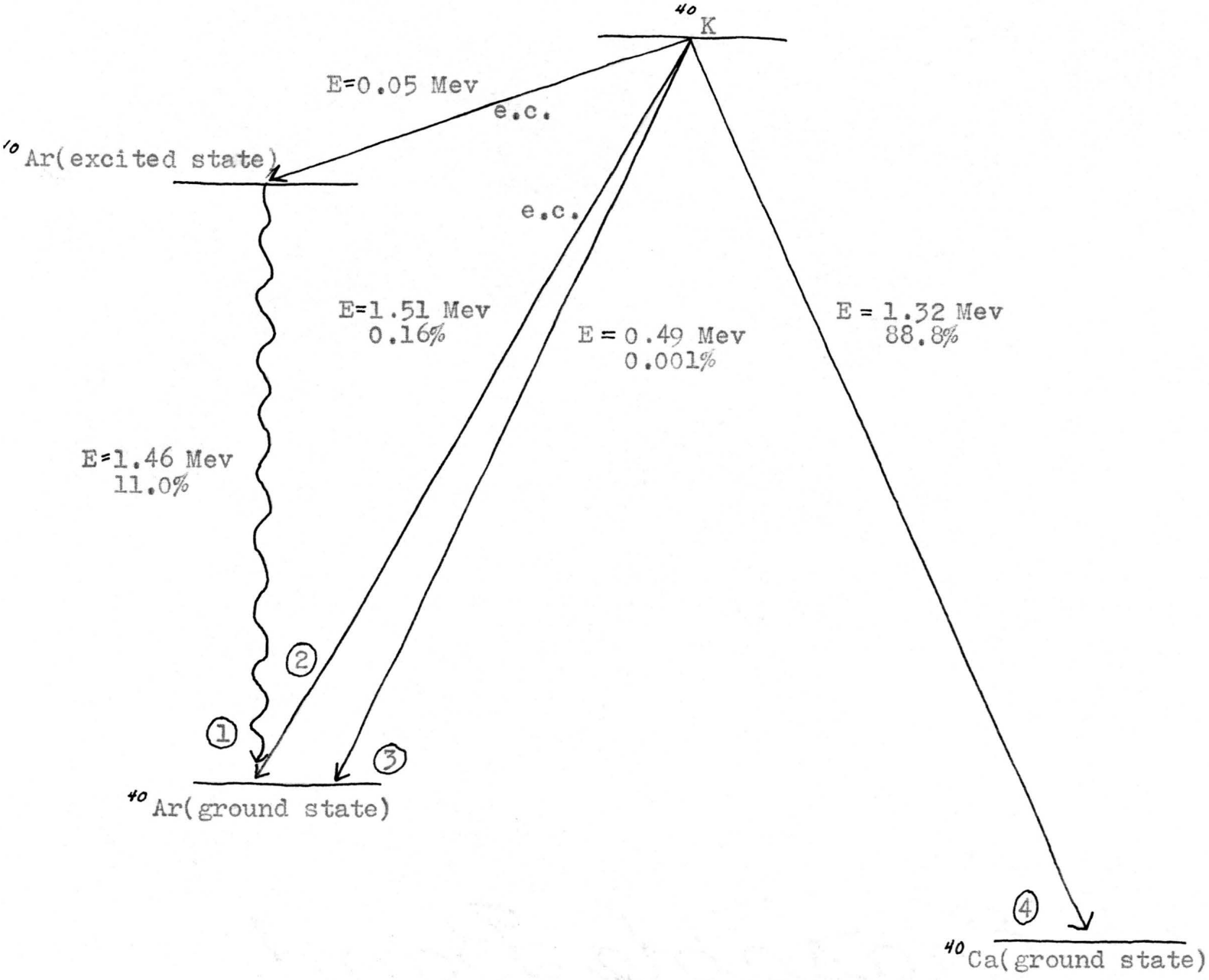



Figure 6. Decay scheme of $^{40}K$. Also indicated are the energy, E, released in each mode of decay and the percentage of $^{40}K$ that decays by each mode. (Dalrymple and Lanphere, 1969)

Equation (6) is known as the K-Ar Age Equation. The decay constants used by most in K-Ar dating are those by Aldrich and Wetherell. They are $\lambda_\epsilon = 0.585 \times 10^{-10}$/yr. and $\lambda_\beta = 4.72 \times 10^{-10}$/yr., thus the total decay constant is $\lambda = \lambda_\epsilon + \lambda_\beta = 5.305 \times 10^{-10}$/yr. Substituting these decay constants into the K-Ar age equation, it becomes:

$$t = 1.885 \times 10^9 \log_e \left[9.068 \left(\frac{^{40}Ar_{rad.}}{^{40}K}\right) + 1\right] \qquad (7)$$

where $1.885 \times 10^9$ = the mean life of $^{40}K$ or simply the average life expectancy of an atom of $^{40}K$. It is the reciprocal of the decay constant. The value 9.068 = branching decay of $^{40}K$ into $^{40}Ar$ and $^{40}Ca$ or the ratio of $^{40}Ar$ to $^{40}Ca$ produced by the decay of $^{40}K$. Therefore the only two quantities needed in order to solve the age equation are $^{40}K$ and $^{40}Ar_{rad.}$.

Five assumptions must also be made whenever using the K-Ar age equation. They are: 1) The decay of $^{40}K$ takes place at a constant rate, regardless of its chemical or physical environment. 2) The present-day proportion of $^{40}K$ to $K_{Total}$ is the same in all materials to which the potassium-argon method is applied. 3) All argon in the rock or mineral is either radiogenic or atmospheric; that is, there is no extraneous argon. 4) The rock or mineral has been a closed system since $t_o$ ; that is, there has been no loss or gain of $^{40}K$ or $^{40}Ar$ except for that which results from the radioactive decay of $^{40}K$. 5) The time of formation of the rock or mineral is short compared to its age(Dalrymple & Lanphere,1969).

Calculations

The necessary data has now been collected and the age can be calculated by two methods, one being manual and the other by

computer. The manual calculations for the biotite sample are shown below and the necessary data can be found in Tables 5, 6, and 7.

Biotite Sample--------5605.5----------Ohio Basement-------Scioto Cty.

1) $K^{+}$ % $= 7.825\times10^{4}$ ppm(for this sample, data taken from Table 5)

$^{40}K/K_{TOTAL} = 1.22\times10^{-4}$ gm/gm sample(constant for all natural K)

CALCULATE $^{40}K$

$^{40}K = K_{TOTAL}\ (1.22\times10^{-4}\ gm/gm)$

$= 7.825\times10^{4}\ (1.22\times10^{-4})$

$^{40}K = \underline{9.5465\ ppm}$

2) Total Ar measured on mass spectrometer:

$^{40}Ar_T = {}^{40}Ar_R + {}^{40}Ar_S + {}^{40}Ar_A$

$^{38}Ar_T = {}^{38}Ar_S + ({}^{38}Ar_A) \Rightarrow {}^{38}Ar_A$ is negligible

$^{36}Ar_T = {}^{36}Ar_A + {}^{36}Ar_S$

where T = total argon present

A = atmospheric argon

S = argon from spike(tracer)

R = radiogenic argon

3) Since $^{38}Ar_S = {}^{38}Ar_T$

CALCULATE $^{38}Ar_S$ (use $^{38}Ar_T$ = peak value-base value)

$^{38}Ar_S = [(0.3844\times1\times10^{4}\ mv.)-(0.001127\times1\times10^{4}\ mv.)$

$= \underline{3832.73\ mv.}$

4) Spike isotopic ratios(measured in a previous experiment)

$^{40}Ar/^{38}Ar = 1.82\times10^{-2}$

$^{36}Ar/^{38}Ar = 1.64\times10^{-2}$

CALCULATE $^{40}Ar_S$ $\qquad$ $^{40}Ar_S = (^{40}Ar/^{38}Ar)_S \ (^{38}Ar)_S$

$^{40}Ar_S = (1.82\times10^{-2})\ (3832.73\ mv.)$

$= \underline{6975.57\times10^{-2}}\ mv.$

CALCULATE $^{40}Ar_T$

$^{40}Ar_T = [(\text{peak value})-(\text{base value})]$

$= [(0.3532\times3\times10^{4}\ mv.)-(0.000206\times3\times10^{4}\ mv.)]$

$= \underline{10589.8\ mv.}$

CALCULATE $^{36}Ar_S$ $\qquad$ $^{36}Ar_S = (^{36}Ar/^{38}Ar)_S \ (^{38}Ar)_S$

$^{36}Ar_S = (1.64\times10^{-2})\ (3832.73\ mv.)$

$= \underline{6285.68\times10^{-2}}\ mv.$

CALCULATE $^{36}Ar_T$

$^{36}Ar_T = [(\text{peak value})-(\text{base value})]$

$= [(0.6676\times100\ mv.)-(0.009637\times100\ mv.)]$

$= \underline{65.79\ mv.}$

5) Atmospheric ratios

$^{40}Ar/^{36}Ar = 300.7$ (measured air argon standard for this sample)

CALCULATE $^{36}Ar_A$

$^{36}Ar_T = {}^{36}Ar_A + {}^{36}Ar_S$

$^{36}Ar_A = {}^{36}Ar_T - {}^{36}Ar_S$

$= 65.79\ mv. - 62.8568\ mv.$

$= \underline{2.93\ mv.}$

CALCULATE $^{40}Ar_A$ $\qquad$ $^{40}Ar_A = (^{36}Ar)_A \ (^{40}Ar/^{36}Ar)_A$

$^{40}Ar_A = (300.7)\ (2.93\ mv.)$

$= \underline{881.05\ mv.}$

6) Sensitivity of the mass spectrometer (moles/mv.)

sensitivity = $^{38}Ar_S$ (moles) / $^{38}Ar_S$ (mv.)

$^{38}Ar$ spike volume = 2.5273 cc STP (measured in separate experiment)

$^{38}Ar$ spike concentration = $20.532 \times 10^{-11}$ moles $^{38}Ar$/cc (measured in separate experiment)

CALCULATE $^{38}Ar_S$ (moles)

$^{38}Ar_S$ = (2.5273 cc STP) ($20.532 \times 10^{-11}$ moles $^{38}Ar$/cc)

= $51.8905 \times 10^{-11}$ moles

CALCULATE SENSITIVITY

sensitivity = ($51.8905 \times 10^{-11}$ moles) ÷ (3832.73 mv.)

= $13.5387 \times 10^{-14}$ moles/mv.

7) $^{40}Ar_T = {}^{40}Ar_R + {}^{40}Ar_S + {}^{40}Ar_A$

CALCULATE $^{40}Ar_R$ (mv.)

$^{40}Ar_R = {}^{40}Ar_T - {}^{40}Ar_S - {}^{40}Ar_A$

= (10589.8 mv.) + (-69.7557 mv. - 881.05 mv.)

= 9638.99 mv.

CALCULATE $^{40}Ar_R$ (moles) (use sensitivity)

$^{40}Ar_R$ (moles) = (9638.99 mv.) ($13.5387 \times 10^{-14}$ moles/mv.)

= $13.05 \times 10^{-10}$ moles

CALCULATE $^{40}Ar_R$ (in moles/gm of sample)

$^{40}Ar_R$ = ($13.05 \times 10^{-10}$ moles) ÷ (0.07805 gm)

= $167.2 \times 10^{-10}$ moles/gm.

CALCULATE $^{40}Ar_R$ (in ppm)

$^{40}Ar_R$ = ($167.2 \times 10^{-10}$ moles/gm) ($4 \times 10^{7}$ gm ppm/moles)

= $668.8 \times 10^{-3}$ ppm.

8) Solve Age Equation

$$t = 1.885\times10^{9}\log_e\left[9.068\left(\frac{^{40}Ar_R}{^{40}K}\right)+1\right]$$

$$= 1.885\times10^{9}\log_e\left[9.068\left(\frac{668.8\times10^{-3}}{9.5465}\right)+1\right]$$

$t = 927$ m.y.

9) CALCULATE % $^{40}Ar_R$ of $^{40}Ar_T - {}^{40}Ar_S$

$$^{40}Ar_R / (^{40}Ar_T - {}^{40}Ar_S \times 100) = (9638.99 \text{ mv.}) \div (10589.8 \text{ mv.} - 69.75 \text{ mv.})$$

$$= 91.6\% \ ^{40}Ar_R$$

The same calculations were made for hornblende but the data for hornblende was used in place of the biotite data. The calculated age for hornblende was 957 m.y., 86.73% $Ar_R$ .

The computer is a much faster way to get the age. A program to take data, make conversions and work equations was already established. The data cards contain the peaks and bases read from the chart for the twelve sets. The computer takes the data and plots it on linear and linear exponential curves. There are two graphs, each containing two curves for each sample, one is 40/38 and the other is 38/36. For each sample, a combination of curves from the two graphs is chosen visually, and from the combinations given, an age can be read. For the biotite, the linear+exponential for 40/38 and linear combination for 38/36 gave an age of 938 $\pm$ 14 m.y. The hornblende, linear+exponential for 40/38 and linear+exponential combination for 38/36 gave an age of 957 $\pm$ 14 m.y. All the resulting age data can be found in Table 8.

## V. Conclusion

The 938 $\pm$ 14 m.y. date for the biotite in this study was not surprising and is in complete agreement with other K/Ar dates on biotite from the Precambrian basement of Ohio. Since no other

Table 5. Data from this experiment necessary for the calculations.

| Mineral | $K^+$ % | Spike Volume | Spike Concentration | Sample Weight |
|---|---|---|---|---|
| Biotite | 7.825 | 2.5273 cc STP | 20.532 10 moles Ar/cc | 0.07805 gm |
| Hornblende | 1.1627 | 2.5761 cc STP | 20.532 10 moles Ar/cc | 0.24835 gm |

Table 6. Data from the ratiometer* for biotite.

| Ar | Peaks | Bases |
|---|---|---|
| $^{40}Ar$ | 0.3532% of 30 volts | 0.000206% of 30 volts |
| $^{38}Ar$ | 0.3844% of 10 volts | 0.001127% of 10 volts |
| $^{36}Ar$ | 0.6676% of 100 mv. | USE AVERAGE { 0.008074% of 100 mv. 0.01120 % of 100 mv. |

Table 7. Data from the ratiometer* for hornblende.

| Ar | Peaks | Bases |
|---|---|---|
| $^{40}Ar$ | 0.5740% of 10 volts | 0.000240% of 10 volts |
| $^{38}Ar$ | 0.4105% of 10 volts | 0.000830% of 10 volts |
| $^{36}Ar$ | 0.702197% of 100 mv. | USE AVERAGE { 0.008508% of 100 mv. 0.006490% of 100 mv. |

* the first set of ratios were used for this age calculation, there are a total of twelve sets of ratios for each sample.

Table 8. Potassium-argon age data.

| Sample # | Mineral | K% | Moles $^{40}Ar_R$/gm(x10$^{-6}$) | $^{40}Ar_R$ % | Age (m.y.) | Sample Locality |
|---|---|---|---|---|---|---|
| 5605.5 | Biotite | 7.825 | 1.6923 | 91.7 | 938±14 | U.S. Steel Well, Scioto Cty. |
| 5605.5 | Hornblende | 1.1627 | 0.25813 | 88.1 | 957±14 | U.S. Steel Well, Scioto Cty. |

K/Ar hornblende dates exist for the Ohio basement, the 957±14 m.y. date obtained in this study is a little difficult to evaluate. It was anticipated at the onset of this project that the hornblende may indeed yield a much older date than the biotite, maybe even as high as 1.4-1.5 b.y. as have been determined in other parts of the Grenville. If the hornblende had been this old, representing only partially reset older basement, the age of 1.2-1.3 b.y. for the volcanics in western Ohio would seem more plausible. It appears from all available data that the volcanics and intercalated sediments lie stratigraphically and/or structurally higher than the metamorphic rocks to the east and west. The 957 m.y. date on the hornblende suggests that if the 1.2-1.3 b.y. date for the volcanics is a meaningful age, then the volcanics(and sediments) are not in place and must have been thrust in sometime post-Grenville and pre-Paleozoic. As has been pointed out before, this is not likely since Grenville-age rocks are present all the way from Illinois to New York. The only other explanation compatible with all isotopic data available seems to be that the volcanics are stratigraphically higher(younger) than the metamorphic rocks and that while the rocks immediately to the east and west of these volcanics have been metamorphosed to at least

amphibolite grade, and probably higher, the volcanics and sediments have not been affected. This would necessitate a very strong metamorphic gradient on either side of the volcanics which is not seen (or maybe the available sampling is just not good enough to delineate this feature). A gradient of this type should result in strongly discordant biotite and hornblende K/Ar dates and it certainly merits the analysis of more biotite-hornblende pairs from samples as close to the volcanics as possible both in Ohio and Indiana. Also, more data from the volcanics and sediments themselves should be gathered, for instance an effort to construct a whole-rock Rb/Sr isochron for these volcanics is a worthwhile project. Any interpretation of the nature of this contact of metamorphics and volcanics hinges on the age of the volcanics.

One thing that can be done with the data from this study is the construction of a model for the post-Grenville pre-Paleozoic tectonic history for the Ohio basement in a manner similar to that presented for another piece of Grenville basement by Dallmeyer, Sutter, and Baker(1975). It is possible, with a few given parameters, to estimate the rate of uplift of the metamorphosed Grenville Province to surface level in Ohio. The given parameters stated: 1) About 1060 m.y. ago, metamorphic temperatures of about 700°C. were realized at a depth of 16 km.(indicating an average geothermal gradient of around 42°C./km.) 2) The hornblende age of 957 m.y. suggests that temperatures had cooled to about 525°C. at this time(argon retention temperature for horn-

blende). 3) The biotite age of 938 m.y. suggests that temperatures had cooled to about 325°C. at this time(argon retention temperatures for biotite). 4) Surface temperatures ~25°C. were realized when the area was exhumed about 650 m.y. ago.

The 42°C./km. geothermal gradient inferred to have prevailed during metamorphism is steep and it has been found that the geothermal gradient better fits a linear decrease pattern from 42°C/km. at 1060 m.y. to 25°C./km. at 650 m.y.(corresponding to a decrease of ~0.04°C./km./m.y.). Assuming the geothermal gradient decreased as suggested and that uplift inititated soon after metamorphism, the following uplift history is suggested, Figure 7.

Following Grenville metamorphism(Figure 7a) the geothermal gradient would have decreased from 42°C./km. to 38°C./km. by 957 m.y., the time at which hornblende would have begun to retain argon at 525°C. at a depth of 13.8 km.(Figure 7b). This would indicate an uplift of 2.2 km. in 103 m.y.(average rate of ~0.02mm/yr). Biotite would have begun to retain argon by 938 m.y. at a temperature of 325°C. The geothermal gradient would have decreased to about 37°C./km.(Figure 7c). The depth would have been about 8.8 km., indicating an uplift of 5 km. in 19 m.y.(average uplift rate of 0.26 mm/yr.). The area was exhumed prior to Early Cambrian time about 650 m.y. and the geothermal gradient would have decreased to the surface temperature of 25°C./km.(Figure 7d). This would require an uplift of 8.8 km. in about 288 m.y.(average uplift rate of 0.03 mm/yr.).

As shown in this model, the rate of uplift between 957 and

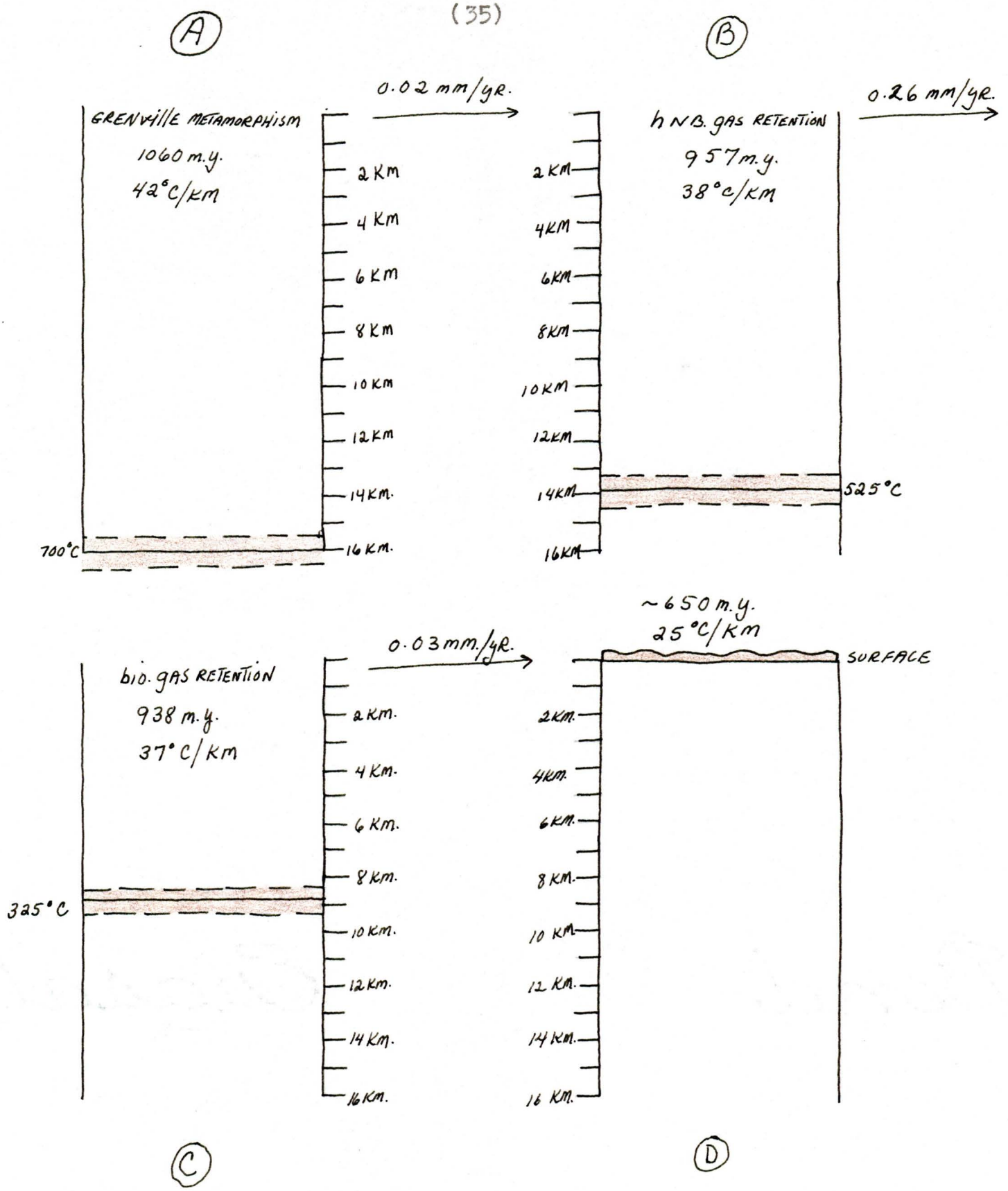



Figure 7. A model of late Precambrian tectonic history for the Ohio basement rock.

938 m.y. was quite rapid when compared to the other rates of uplift in other time intervals suggesting this interval was a time of active tectonism with probable increase in erosion rates and/or a temporary topographic high. The area was exposed to erosion for some time since the lower Cambrian unconformably overlies the Precambrian terrane.

A model, as above, has been worked out for the Reading Prong area of the Appalachians by Dallmeyer, Sutter, and Baker(1975) using the ages of 900 m.y. for the hornblende and 790 m.y. for the biotite. Following similar parameters, the rates of uplift were 0.01 mm/yr. for the interval from 1060 m.y. to 900 m.y., 0.03mm/yr. for the interval from 900 m.y. to 790 m.y. and 0.07mm/yr. for the 790 m.y. to 650 m.y. interval. When compared to the results from Ohio, the uplift in the east seemed to be a slow, continuous increase whereas to the west(Ohio) the uplift was more rapid in parts and not a continuous increase in uplift. Because these two areas involve the Grenville Province and the rates of uplift in each area, it is possible that these two areas were involved in the same uplift with the hinge of the uplifted block being on the western edge of the Grenville Province where rapid uplift occured early compared to the eastern margin followed by extremely slow uplift in the west and accelerating rates to the east in the Late Proterozoic. The further suggestion is that uplift rates were fast enough in the Ohio area about 950 m.y. ago to create a Grenville mountain chain, but on the eastern margin of the province uplift rates never reached the levels needed to create high topography.

## References

Bass, Manual N., 1960, Grenville Boundary in Ohio; Journal of Geology, v. 68, no. 6, p. 673-677.

Dallmeyer, R.D., Sutter, J.F., and Baker, D.J., 1975, Incremental $^{40}Ar/^{39}Ar$ ages of biotite and hornblende from the northeastern Reading Prong: Their bearing on late Proterozoic thermal and tectonic history; Geological Society of America Bulletin, v. 86, p. 1435-1443.

Dalrymple, G.B. and Lanphere, M.A., 1969, Potassium-Argon Dating, W.H. Freeman & Company, San Francisco, p. 258.

Gonterman, James R., 1973, Petrographic Study of the Precambrian Basement Rocks of Ohio; Ohio State University Masters Thesis (unpublished), copy 2, p. 140.

Hofmann, C.M., Faure, G., and Janssens, A., 1972, Age Determination of a Granite Gneiss from the Precambrian Basement of Scioto County, Ohio; Ohio Journal of Science, v. 72, no. 1, p. 49-53.

Lidiak, E.G., Marvin, R.F., Thomas, H.H., and Bass, M.N., 1966, Geochronology of the midcontinent region, United States; 4. Eastern area; Journal of Geophysical Research, v. 71, no. 22, p. 5427-5438.

McCormick, George R., 1961, Petrology of Precambrian Rocks of Ohio; Report of Investigations, no. 41, p. 60.

McLaughlin, Dean B., 1954, Suggested Extension of the Grenville Orogenic Belt and the Grenville Front; Science, v. 120, p. 287-289.

Owens, Gordon L., 1967, The Precambrian Surface of Ohio; Report of Investigations, no. 64, p. 8.

Summerson, Charles H., 1962, Precambrian in Ohio and Adjoining Areas; Report of Investigations, no. 44, p. 16.

Vargo, Robert T., 1972, Sr-Rb Age Determination of a Precambrian Rock from Lake County, Ohio; Ohio State University Senior Thesis (unpublished), p. 16.